Task Parallelism
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Task Parallelism
Defining our Terms

**Task:** a unit of computation that can/should execute in parallel with other tasks

**Thread:** a system resource that executes tasks
- not exposed in the language
- occasionally exposed in the implementation

**Task Parallelism:** a style of parallel programming in which parallelism is driven by programmer-specified tasks

(in contrast with):

**Data Parallelism:** a style of parallel programming in which parallelism is driven by computations over collections of data elements or their indices
Task Parallelism: Begin Statements

// create a fire-and-forget task for a statement
begin writeln("hello world");
writeln("goodbye");

Possible outputs:

- hello world
- goodbye
- hello world
- goodbye
Task Parallelism: Cobegin Statements

```c
// create a task per child statement
cobegin {
    producer(1);
    producer(2);
    consumer(1);
} // implicit join of the three tasks here
```
Cobegins/Serial by Example: QuickSort

```plaintext
proc quickSort(arr: [?D],
    depth = 0,
    thresh = log2(here.maxTaskPar),
    low: int = D.low,
    high: int = D.high) {

    if high - low < 8 {
        bubbleSort(arr, low, high);
    } else {
        const pivotVal = findPivot(arr, low, high);
        const pivotLoc = partition(arr, low, high, pivotVal);
        serial (depth >= thresh) do cobegin {
            quickSort(arr, depth+1, thresh, low, pivotLoc-1);
            quickSort(arr, depth+1, thresh, pivotLoc+1, high);
        }
    }
}
```
Cobegins/Serial by Example: QuickSort

```c
proc quickSort(arr: [?D],
               low: int = D.low,
               high: int = D.high) {
    if high - low < 8 {
        bubbleSort(arr, low, high);
    } else {
        const pivotVal = findPivot(arr, low, high);
        const pivotLoc = partition(arr, low, high, pivotVal);
        serial (here.runningTasks > here.maxTaskPar) do
            cobegin {
                quickSort(arr, low, pivotLoc-1);
                quickSort(arr, pivotLoc+1, high);
            }
    }
}
```
Task Parallelism: Coforall Loops

// create a task per iteration
coforall t in 0..#numTasks {
    writeln("Hello from task ", t, " of ", numTasks);
} // implicit join of the numTasks tasks here

writeln("All tasks done");

Sample output:

Hello from task 2 of 4
Hello from task 0 of 4
Hello from task 3 of 4
Hello from task 1 of 4
All tasks done
Comparison of Begin, Cobegin, and Coforall

begin:
- Use to create a dynamic task with an unstructured lifetime
- “fire and forget” (or at least “leave running for awhile”)

cobegin:
- Use to create a related set of heterogeneous tasks
  ...or a small, fixed set of homogenous tasks
- The parent task depends on the completion of the tasks

coforall:
- Use to create a fixed or dynamic # of homogenous tasks
- The parent task depends on the completion of the tasks

Note: All these concepts can be composed arbitrarily
Task Parallelism: Data-Driven Synchronization

- **sync variables**: store full-empty state along with value
  - by default, reads/writes block until full/empty, leave in opposite state

- **atomic variables**: support atomic operations
  - e.g., compare-and-swap; atomic sum, multiply, etc.
  - similar to C/C++
begin producer();
consumer();

// 'sync' types store full/empty state along with value
var buff$: [0..#buffersize] sync real;

proc producer() {
  var i = 0;
  for … {
    i = (i+1) % buffersize;
    buff$[i] = …;  // wait for empty, write, leave full
  }
}

proc consumer() {
  var i = 0;
  while … {
    i = (i+1) % buffersize;
    …buff$[i]...;  // wait for full, read, leave empty
  }
}
Synchronization Variables

- **Syntax**
  
  ```
  sync-type: 
  sync type
  ```

- **Semantics**
  - Stores *full/empty* state along with normal value
  - Initially *full* if initialized, *empty* otherwise
  - Default read blocks until *full*, leaves *empty*
  - Default write blocks until *empty*, leaves *full*

- **Examples: Critical sections and futures**

  ```
  var lock$: sync bool;
  lock$ = true;
  critical();
  var lockval = lock$;
  ```

  ```
  var future$: sync real;
  begin future$ = compute();
  res = computeSomethingElse();
  useComputedResults(future$, res);
  ```
Synchronization Variable Methods

- **readFE()**: block until *full*, leave *empty*, return value
- **readFF()**: block until *full*, leave *full*, return value
- **readXX()**: return value (non-blocking)
- **writeEF(v)**: block until *empty*, set value to *v*, leave *full*
- **writeFF(v)**: wait until *full*, set value to *v*, leave *full*
- **writeXF(v)**: set value to *v*, leave *full* (non-blocking)
- **reset()**: reset value, leave *empty* (non-blocking)
- **isFull**: return *true* if full else *false* (non-blocking)

**Defaults**: read: **readFE**, write: **writeEF**
Single Variables

- **Syntax**
  
  \[
  \textit{single-type:} \quad \textit{single type}
  \]

- **Semantics**
  
  - Similar to sync variable, but stays \textit{full} once written

- **Example: Multiple Consumers of a future**
  
  ```
  var future$: single real;
  begin future$ = compute();
  begin computeSomethingElse(future$);
  begin computeSomethingElse(future$);
  ```
Single Type Methods

- **readFE()**: block until full, leave empty, return value
- **readFF()**: block until full, leave full, return value
- **readXX()**: return value (non-blocking)
- **writeEF(v:t)**: block until empty, set value to v, leave full
- **writeFF(v:t)**: wait until full, set value to v, leave full
- **writeXF(v:t)**: set value to v, leave full (non-blocking)
- **reset()**: reset value, leave empty (non-blocking)
- **isFull: bool**: return true if full else false (non-blocking)

**Defaults**: read: readFF, write: writeEF
Atomic Variables

● Syntax

```plaintext
atomic-type:
  atomic type
```

● Semantics
  ● Supports operations on variable atomically w.r.t. other tasks
  ● Based on C/C++ atomic operations

● Example: Trivial barrier

```plaintext
var count: atomic int, done: atomic bool;
proc barrier(numTasks) {
  const myCount = count.fetchAdd(1);
  if (myCount < numTasks - 1) then
    done.waitFor(true);
  else
    done.testAndSet();
}
```
Atomic Methods

- **read()**: return current value
- **write(v)**: store v as current value
- **exchange(v)**: store v, returning previous value
- **compare_exchange(old, new)**: store new iff previous value was old; returns true on success
- **wait_for(v)**: wait until the stored value is v
- **add(v)**: add v to the value atomically
- **fetch_add(v)**: same, returning pre-sum value
  \( (\text{sub, or, and, xor} \text{ also supported similarly}) \)
- **test_and_set()**: like exchange(true) for atomic bool
- **clear()**: like write(false) for atomic bool
Comparison of Synchronization Types

**sync/single:**
- Best for producer/consumer style synchronization
  - “this task should block until something happens”
- use single for write-once values

**atomic:**
- Best for uncoordinated accesses to shared state
  - “these tasks are unlikely to interfere with each other, at least for very long…”
Task Intents

● Tells how to “pass” variables from outer scopes to tasks
  ● Similar to argument intents in syntax and philosophy
    ● also adds a “reduce intent”, similar to OpenMP
  ● Design principles:
    ● ”principle of least surprise”
    ● avoid simple race conditions
    ● avoid copies of (potentially) expensive data structures
    ● support coordination via sync/atomic variables

● Congruent to forall intents, but for task-parallel constructs
Task Intent Examples

```plaintext
var sum: real;
coforall i in 1..n do  // default task intent of scalars is ‘const in’
    sum += computeMyResult(i);  // so this is illegal: (and avoids a race)

var sum: real;
coforall i in 1..n with (ref sum) do  // override default task intent
    sum += computeMyResult(i);  // we’ve now requested a race

var sum: real;
coforall i in 1..n with (+ reduce sum) do  // override default intent
    sum += computeMyResult(i);  // per-task sums will be reduced on task exit

var sum: atomic real;
coforall i in 1..n do  // default task intent of atomics is ‘ref’
    sum.add(computeMyResult(i));  // so this is legal, meaningful, and safe
```
Questions about Task Parallelism in Chapel?
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